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September 20, 2000
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ASSISTANT COMMISSIONER FOR PATENTS
BOX PATENT APPLICATION
WASHINGTON, D.C. 20231

UTILITY PATENT APPLICATION TRANSMITTAL
Under 37 CFR 1.53(b)

Transmitted herewith for filing is the patent application of

INVENTOR(S): Danelle Mary Tanner and James Joe Allen

FOR: Micromechanical Apparatus for Measurement of Forces

I. APPLICATION ELEMENTS

1. ☒ Fee Transmittal Form (original + duplicate)

2. ☒ Specification
   Total Pages _13___

3. ☒ Drawings
   Total Sheets __1___

4, ☒ Oath or Declaration (with Power of Attorney) Total Pages __2__
   a. ☒ Newly Executed
   b. ☐ Copy from Prior Application (Continuation or Divisional)

   ☐ Deletion of Inventors
   Signed Statement Attached Deleting Inventor(s) named in prior Application. 37 CFR 1.63(d)(2) and 1.33(b).

5. ☐ Incorporation by Reference (if Box 4b is checked). The entire disclosure of the prior application(s) from which a copy of the Oath or Declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

6. ☐ Microfiche Computer Program (Appendix)

II. ACCOMPANYING APPLICATION PARTS

7. ☐ Assignment Papers (cover sheet and document(s)

8. ☐ 37 CFR 3.73(b) Statement (where there is an assignee) ☒ Power of Attorney (with the Declaration)

9. ☐ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations

10. ☐ Preliminary Amendment

11. ☒ Return Receipt Postcard (Itemized)

12. ☐ Other

III. IF A CONTINUING APPLICATION

☐ Continuation ☐ Divisional ☐ Continuation-in-Part (CIP)

of prior application No. __/____________

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CERTIFICATION UNDER 37 CFR 1.10

I hereby certify that this New Application Transmittal and the documents referred to as enclosed therein are being deposited with the U. S. Postal Service on, September 20, 2000, in an envelope as "Express Mail Post Office to Addressee" Mailing Label Number EL027382422US addressed to the: Assistant Commissioner for Patents, Box Patent Application, Washington, D.C. 20231.

Mary Loukota
Mary Loukota

PTO/SB/17 (12-98)
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FEE TRANSMITTAL FOR FY 2000

Patent fees are subject to annual revision.
Small Entity payments must be supported by a small entity statement, Otherwise large entity fees must be paid See Forms PTO/SB/09-12.

TOTAL AMOUNT OF PAYMENT	($) ***690.00***

Complete if Known	
Application Number	
Filing Date	9/20/00
First Named Inventor	Danelle Mary Tanner, et. al.
Examiner Name	
Group / Art Unit	
Attorney Docket No.	SD6483/S93721

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09/20/00

METHOD OF PAYMENT (check one)

1. ☒ The Commissioner is hereby authorized to charge indicated fees and credit any over payments to:

Deposit Account Number: 19-0131

Deposit Account Name: Sandia National Labs

☐ Charge Any Additional Fee Required Under 37 CFR 1.16 and 1.17

2. Payment Enclosed:
☐ ☐ Check ☐ Money Order ☐ Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	690	201	345	Utility filing fee	690.
106	310	206	155	Design filing fee	
107	480	207	240	Plant filing fee	
108	760	208	380	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) $ 690.00

2. EXTRA CLAIM FEES

		Extra Claims		Fee from below		Fee Paid
Total Claims	14	-20**=	X	18.00	=	0
Independent Claims	1	- 3**=	X	78	=	0
Multiple Dependent					=	

**or number previously paid, if greater, For Reissues, see below

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	78	202	39	Independent claims in excess of 3
104	260	204	130	Multiple dependent claim, if not paid
109	78	209	39	**Reissue independent claims over original patent
110	18	210	9	**Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($)0

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge – late filing fee or oath	
127	50	227	25	Surcharge – late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840	11	1,840	Requesting publication of SIR after Examiner	
115	110	215	55	Extension for reply within first month	
116	380	216	90	Extension for reply within second month	
117	870	217	435	Extension for reply within third month	
118	1,360	218	680	Extension for reply within fourth month	
128	1,850	228	925	Extension for reply within fifth month	
119	300	219	150	Notice of Appeal	
120	300	220	150	Filing a brief in support of an appeal	
121	260	221	130	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,210	241	605	Petition to revive - unintentional	
142	1,210	242	605	Utility issue fee (or reissue)	
143	430	243	215	Design issue fee	
144	580	244	290	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	690	246	345	Filing a submission after final refection (37 CFR 1.129(a))	
149	690	249	345	For each additional invention to be examined (37 CFR 1 129(b))	
				Other fee (specify) ______	
				Other fee (specify) ______	

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($)

SUBMITTED BY

Typed or Printed Name	Brian W. Dodson			Reg. Number	39,170
Signature	Brian W. Dodson	Date	9/20/2000	Deposit Account User ID	19-0131

Complete (if applicable)

Burden Hour Statement This form is estimated to take 0 2 hours to complete Time will vary depending upon the needs of the individual case Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer, Patent and Trademark Office, Washington, DC 20231 DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS SEND TO Assistant Commissioner for Patents, Washington, DC 20231.

SD6483/S93721
September 20, 2000

Micromechanical Apparatus for Measurement of Forces

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Micromechanical Apparatus for Measurement of Forces

GOVERNMENT RIGHTS

This invention was made with Government support under Contract DE-AC04-94AL85000 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

FIELD OF THE INVENTION

The present invention relates generally to force measurement instrumentation, and more particularly to instrumentation adaptable to the special challenges of micromechanical applications.

BACKGROUND OF THE INVENTION

The development of practical micromechanical devices which can be operated reliably and manufactured routinely and with high process yield is currently hampered by a virtual absence of standard diagnostic instrumentation. Such fundamental parameters as physical structure, displacement distance, spring constants, fracture strength, forces, and many others cannot at present be measured routinely. Relative values for such parameters can at times be inferred from operating voltage, measured capacitance, and the like, but such indirect estimates fail badly when absolute accuracy is needed.

Among the practical problems generated by this lack are the difficulty of efficiently designing a set of devices which are intended to function properly and reliably with each

other. Owing to process variations and independent development, a device which in its ideal design will take 8 μNewtons to operate and an actuator which ideally will deliver 12 μNewtons may not function properly together when integrated into and fabricated on a single chip. Modification of the fabrication process also can result in unexpected changes in functionality for complex devices. The ability to measure absolute fundamental material and device properties would greatly reduce the time and expense required to make such adjustments.

Several approaches exist to estimate relative forces in specific situations. For example, for a parallel plate electrostatic actuator, the output force can be estimated given the area of the plates, the voltage difference between the plates, and the distance between the plates. In most cases, this works fairly well for large plates and near-zero displacements. However, because no technique exists to directly calibrate the force produced by such an actuator, many potentially defective assumptions must be made to calculate the actuator force. Among these are that the areas for the plates are correct, that the plates are flat, that the plates are parallel, that the plate supports have not warped from residual stress (which could change the plate's separation at rest), that doping or interlayer electrical difficulties do not reduce the voltage or charge being applied to the plates, and so on. With most of these problems, the actuator will give 4 times the force when twice the voltage is applied, so relative measurements can be made using this approach, but absolute measurements do not presently appear practical.

Another approach which has been used is to measure the bending of a cantilever under an applied force. The equations describing the bending of a cantilever are then used to extract the force being applied. This approach has a number of problems. As before, assumptions concerning the dimensions and structure of the cantilever and its anchor have to be made to do the analysis.

Beyond that, the strain acting on a bent cantilever is highly inhomogeneous owing to the stress concentration associated with the cantilever anchor. The response of the cantilever therefore depends sensitively on structural flaws, particularly those which may exist near the anchoring structure.

Also, the strains encountered in making practical force measurements in the realm of micromechanical devices are sufficiently large that the material from which the cantilever and at least part of its support are made exhibit nonlinear mechanical responses. This factor complicates the analysis, and makes the measurement even more susceptible to process variations and similar unintended factors.

Accordingly, there is a long-felt need for a micromechanical device which can measure absolute forces with reasonable accuracy. Ideally, such a device would be integrable with production microelectromechanical systems (MEMS), and could be calibrated independent of other MEMS devices. Further, interpreting the output of such a device would be simplified if the basic design required limited

material strain for operation. Finally, real-time diagnostics for proper functioning of the device would be useful.

SUMMARY OF THE INVENTION

A new class of micromechanical dynamometers is disclosed. The combination of the small size scale and the enormous strength of micromechanical materials allows a wide range of applied forces to be measured directly. These dynamometers can be externally calibrated against a reference.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1. Side 1a), top(1b), and front (1c) views of a micromechanical dynamometer after the instant invention.

Figure 2.

DETAILED DESCRIPTION

A specific implementation of a micromechanical dynamometer after the instant invention appears in Figure 1, where Figure 1a is the side view, Figure 1b is a top view, and Figure 1c is a front view of the dynamometer.

Anchor 101 is located on substrate 100. A deflection element comprising anchor site 103, stress deformation ring 102, and input site 104, is then affixed to anchor 101. As shown, the stress deformation ring 102 is essentially parallel to the surface of substrate 100. Ring constraints 105 and 106 comprise a notch within which ring 102 is free to move, and as shown also comprise a distance scale, so that deformation of ring 102 in response to forces applied to input site 104 can be optically measured.

Force coupler 107 (in this case a simple rod) allows a convenient connection to forces generated external to the dynamometer, and comprises indicator 108, which indicates the amount of stretching of ring 102 in response to such external force. Force coupler 107 moves within the constraint of motion guides 110 and 111, which are mounted on scale body 109, which also comprises a distance scale for quantitative optical measurement of ring 102 stretching. Force coupler 107 can also comprise a calibration force input, which comprises a hole 113 in an extension 112 of force coupler 107, said hole being suitable for applying a calibration force using a nanoindenter or similar external equipment.

The dynamometer shown in Figure 1, and many variations thereof, can conveniently be fabricated from a series of patterned thin film layers along with microelectromechanical devices. Materials which can be used in such apparatus include crystalline silicon, polysilicon, amorphous silicon, silicon oxide, silicon nitride, amorphous diamond, sol-gel glasses.

In use, an external force is coupled to force coupler 107. The external force will be assumed to pull force coupler 107 away from ring 102. In response to this force, the diameter of ring 102 along the axis of force coupler 107 increases, and the diameter of ring 102 perpendicular to that axis decreases. The changes in these diameters can be determined by optical inspection of the distance scales. The resulting displacement measurements can then be converted into a force magnitude by using a calibration equation.

The deflection element, comprising a set of anchor sites and a set of input sites, is preferably a high-compliance deflection element. By high-compliance is meant that the deflection element has an effective spring constant much smaller than that of an equivalent solid deflection element. In essence, the holes and other features introduced into a high-compliance deflection element introduce low-stiffness bending modes into an otherwise solid deflection element, and these low-stiffness bending modes dramatically decrease the effective spring constant. For example, in the implementation of figure 1, the ring 102 can easily elongate under applied stress - typically orders of magnitude more easily than if the ring were replaced by a solid disk. Note that many shapes and

configurations beside the annulus or ring can be used to obtain a high-compliance deflection element.

The discussion above of specific implementations of the instant invention is for purposes of exposition only. The limitations inherent or explicit therein are not intended to limit the scope of the instant invention. That scope is set by the claims in view of the specification.

Claims

1. A micromechanical dynamometer, comprising:
   a) a substrate;
   b) a high-compliance deflection element comprising at least one anchor site and at least one input site;
   c) one anchor for each anchor site, extending between the substrate and said anchor site;
   d) a force coupler transferring force from an external source to at least one input site; and,
   e) a displacement gauge functionally attached to the high-compliance deflection element.
2. The dynamometer of claim 1, wherein the high-compliance deflection element comprises crystalline silicon, polycrystalline silicon, amorphous silicon, silicon oxide, silicon nitride, amorphous diamond, or a sol-gel glass.
3. The dynamometer of claim 1, wherein the high-compliance deflection element comprises an annulus of material, said annulus having the shape of a polygon, and essentially constant thickness normal to said polygon.
4. The dynamometer of claim 3, wherein said high-compliance deflection element has a line of mirror symmetry.
5. The dynamometer of claim 3, wherein said polygon is a regular polygon.
6. The dynamometer of claim 1, wherein the high-compliance deflection element comprises a circular

annulus, said annulus having a rectangular cross-section of essentially constant dimensions throughout.

7. The dynamometer of claim 1, wherein said displacement gauge comprises an indicator mechanically coupled to displacements of the high-compliance deflection element.

8. The dynamometer of claim 7, wherein said displacement gauge comprises multiple indicators mechanically coupled to displacements of the high-compliance deflection element, each such indicator being coupled to a different point on the deflection element.

9. The dynamometer of claim 7, wherein said displacement gauge further comprises an optically readable distance scale positioned so that displacement of the indicator can thereby be quantified optically.

10. The dynamometer of claim 1, further comprising a calibration force input.

11. The dynamometer of claim 10, wherein the calibration force input is integral with the force coupler.

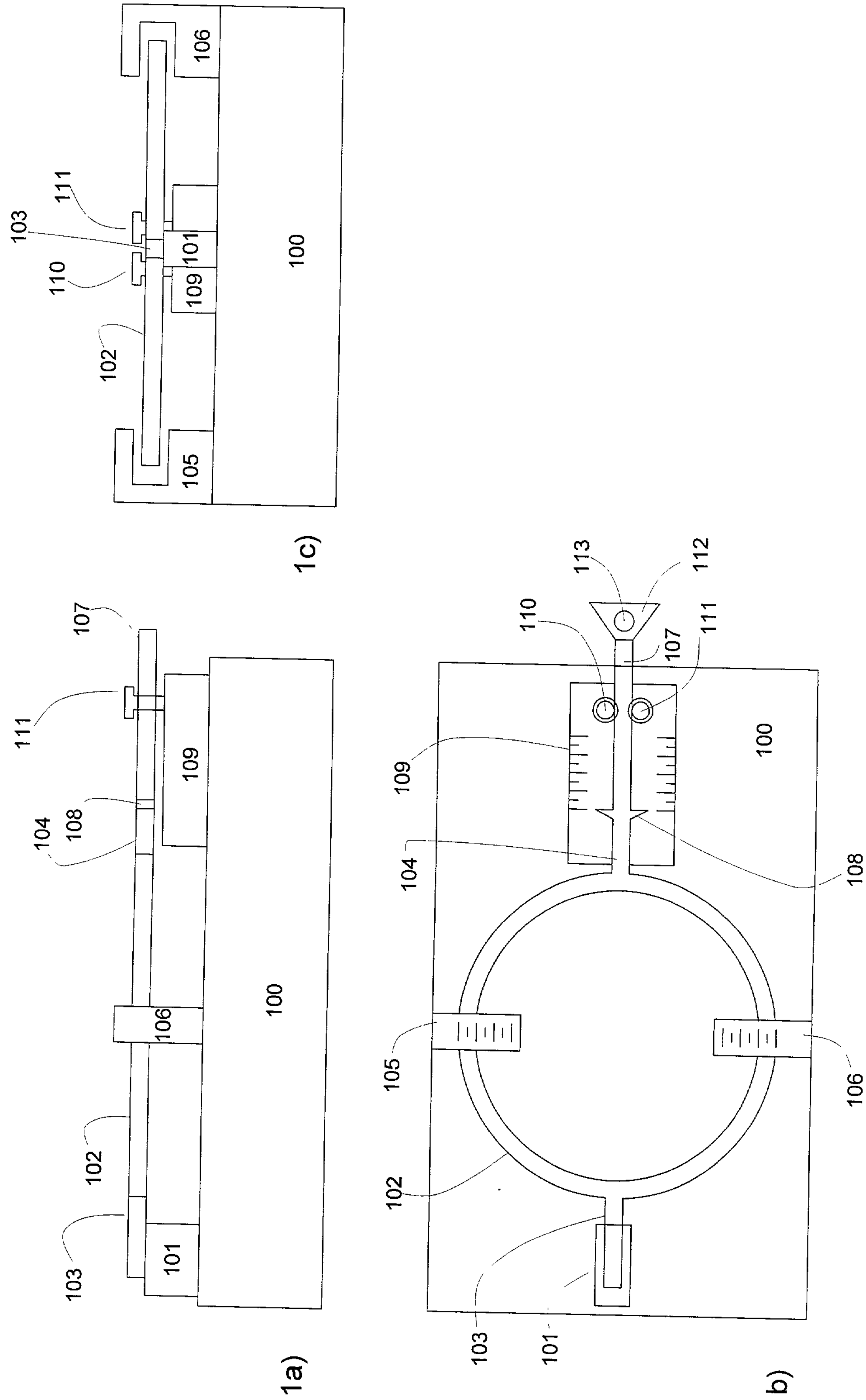
12. The dynamometer of claim 1, further comprising a deflection element restraint system.

13. The dynamometer of claim 12, wherein said restraint system comprises motion guides.

14. The dynamometer of claim 13, wherein said restraint system comprises ring constraints.

Abstract

A new class of micromechanical dynamometers has been disclosed, said dynamometers being particularly suited to fabrication in parallel with microelectromechanical apparatus. Forces in the microNewton regime and below can be measured with such instrumentation.



1a)

1b)

1c)

Figure 1

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September 20, 2000
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COMBINED DECLARATION AND POWER OF ATTORNEY

As the below-named inventor(s): **Danelle Mary Tanner and James Joe Allen**

I/We hereby declare that:

My/Our residence(s), post office address(es), and citizenship(s) are as stated below next to my/our name(s).

I/We believe I/we am/are the original, first, and sole inventor (if only one name is listed below) or an original, first, and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **Micromechanical Apparatus for Measurement of Forces**, the specifications of which (check one)

__X___ is attached hereto
______ was filed on ___________________ as Serial No.________________ and was amended on _________________________ (if applicable).

I/We hereby state that I/we have reviewed and understand the contents of the above-identified specification, including the claims as amended by any amendment referred to above.

I/We acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I/We hereby claim foreign priority benefits under Title 35, United States Code § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION

Priority Claimed

YES	
NO	X

Number Country Filed (Day/Month/Year)

I/We hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

______________NONE____

Serial No. Filing Date Status

POWER OF ATTORNEY: As the named inventors, we hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

Names and Registration Nos.		Names and Registration Nos.	
Timothy D. Stanley	30,428	Gregory A. Cone	28,835
George H. Libman	27,984	Brian W. Dodson	39,170
Kurt C. Olsen	29,961	John P. Hohimer	39,226
Russell D. Elliott	35,497	Timothy P. Evans	41,013
V. Gerald Grafe	42,599	Elmer A. Klavetter	42,743
Robert D. Watson	45,604		

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SANDIA NATIONAL LABORATORIES Patent & Licensing Center P. O. Box 5800 - MS-0161 Albuquerque, New Mexico 87185-0161	Brian W. Dodson (505) 844-5909

(I)/We hereby declare that all statements made herein of my/our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Inventor Name Danelle Mary Tanner Citizenship: USA

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